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Abstract

Alternative Energy is becoming a popular and an essential energy resource in the current century. This paper investigates the effect of using a hybrid microgrid system in Langkawi and Socotra Islands. Configuration of the optimal hybrid system is selected based on the best components and its sizing with appropriate operation strategy to provide a cheap efficient, reliable and cost effective system. The total net present cost for the two Islands has been determined using HOMER program based on the Island's data. This finding will help to install sources of renewable energy in places that will ensure low cost and performance of hybrid systems. The comparison of the annual yield for renewable energy with the cost of production considering pollution is an important factor that can be used to develop an environmentally safer and cleaner renewable energy source

Keywords

langkawi, application, microgrid, islands, study, socotra, feasibility

Disciplines

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Feasibility Study of Microgrid Application in Langkawi and Socotra Islands

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Abstract--Alternative Energy is becoming a popular and an essential energy resource in the current century. This paper investigates the effect of using a hybrid microgrid system in Langkawi and Socotra Islands. Configuration of the optimal hybrid system is selected based on the best components and its sizing with appropriate operation strategy to provide a cheap efficient, reliable and cost effective system. The total net present cost for the two Islands has been determined using HOMER program based on the Island's data. This finding will help to install sources of renewable energy in places that will ensure low cost and performance of hybrid systems. The comparison of the annual yield for renewable energy with the cost of production considering pollution is an important factor that can be used to develop an environmentally safer and cleaner renewable energy source.

Index Terms – Microgrid, Hybrid systems, Renewable energy, Load demand

I. INTRODUCTION

Today's renewable energy system has become an evolution in the world of electrical systems. The system, a major fossil fuel consumer and emitter of greenhouse gases, is not well suited to distributed renewable solar and wind energy sources and does not have sufficient capacity to meet future demand. Consequently, new technology and structure of power supply network is important where the load will continue to receive power if there is a disconnection from utility. Therefore, microgrid is important in the electrical power generation. It is a group of loads and distributed generation system in a common local area. It can operate in an islanded mode even though there are disturbances on the grid. Microgrid basically has three important components namely wind or photovoltaic (PV) generator, inverter with constant voltage source and loads. Wind or PV is the common renewable energy source used in micro grid [1].

An increasing interest in renewable energy resources has been observed for several years. The unconventional energy sources are non-polluting, free in their availability, and continuous. These facts make the alternative resources attractive for many applications. However, renewable energy

sources have unpredictable random behaviors, while, some of them, such as solar radiation and wind speed, have complementary profiles. The exploitation of energy sources such as wind and photovoltaic energy is becoming necessary and profitable. In developing countries, this exploitation has a vital range which goes beyond reducing the oil bill [2]. The use of renewable energy technology to meet energy demands has been steadily increasing over the years. Because of the alternating characteristics of solar irradiation and wind speed, which greatly influence the resulting energy production, the major aspects in the design of PV, wind generator and power generation systems are the reliable supply of power to consumers under varying atmospheric conditions and the corresponding cost of the total system [3]. The advantage of a hybrid system is that, when one power source is at low levels the other source is usually at higher levels. On a cloudy, windy day when solar panels are producing lower levels of energy a wind generator may be producing a lot of energy. Similarly, to use a wind generator effectively requires a location, which has a certain amount of wind on a regular basis.

The distribution generations such as wind turbines, photovoltaic cells, micro-turbines and fuel cells are typically located in microgrid to improve the reliability and power quality. During peak condition, it will also benefit local utilities by providing adequate power to the loads. The protection and control of the microgrid are required to meet the changes of local generators or energy storage units into the distribution generation. When the microgrid is operating in the islanded mode, short circuit current will be changed significantly. Therefore, a proper strategy control and protection techniques has to be implemented towards microgrid [4]. The performance of possible variants and the effect of energy demand management on PV–wind–diesel–battery system were investigated in Refs. [5-7]. the simulation of a real hybrid PV–wind–diesel–battery system located in Alaska was applied in Ref. [8]. A PV–wind–diesel–battery system for remote areas in the far Northern Province of Cameroon was designed in Ref. [9].

In rural Malaysia and Yemen, some areas are still not connected to the national grid and powered by stand-alone sources such as diesel generators. With the current increase in oil prices and the decreasing subsidy of the government to diesel, pressure is mounting on rural people who rely heavily in their power requirements on diesel. To help release this burden and improve the quality of lives of rural people, stand-alone power system based on hybrid energy system backed up by diesel generator or national grid is needed. Thus, this paper is focusing on the economic impact and environmental benefits of

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using hybrid microgrid system in two Islands, Langkawi and Socotra. The paper is organized as such that, section 2 describes the renewable resources and load demand in Langkawi and Socotra Islands. In section 3, the modeling of microgrid system is discussed. Results and conclusion are given in section 4 and 5 respectively.

II. RENEWABLE RESOURCES AND LOAD DEMAND

The two islands considered in this study are located in different regions on Indian Ocean. Langkawi is a part of Malaysia; it is an archipelago of 99 islands in the Andaman Sea which is a part of the Indian Ocean, some 30 km off the mainland coast of northwestern Malaysia. Socotra is a part of Yemen; it is a small archipelago of four islands in the Indian Ocean. The largest island also called Socotra. It lies off some 240 kilometres east of the Horn of Africa and 380 kilometres south of the Arabian Peninsula. The two maps of Langkawi and Socotra islands are shown in Figure 1 and 2 respectively.



Fig. 1. Map of Langkawi Island

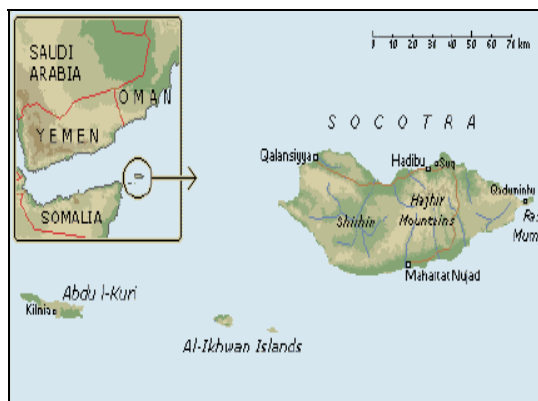


Fig. 2. Map of Socotra Island

The load demands of both Islands differ from each other based on the type of consumer and location as seen in Table 1. Figures 3 and 4 show the daily and monthly loads profile of Langkawi Island, the peak load in the island is 8.76kW and the load factor which is the average load divided by the peak load is 0.299. The scaled annual average load demand is 63kWh/d. The daily global horizontal radiation and the clearness index of the island are depicted in Figure 5. As for the synthesized data of the monthly wind speed, it is shown in Figure 6. Similarly,

the daily and monthly loads profile of Socotra Island is illustrated in Figures 7 and 8. The peak load of the island is 1.78kW and the load factor is 0.399. The scaled annual average load demand is 17kWh/d. The daily global horizontal radiation with clearness index and the monthly wind speed are seen in Figure 9 and 10 respectively.

TABLE I
LOAD DEMAND

| Location | Load Demand |
|-----------------|-------------|
| Langkawi Island | 63kWh/d |
| Socotra Island | 17kWh/d |

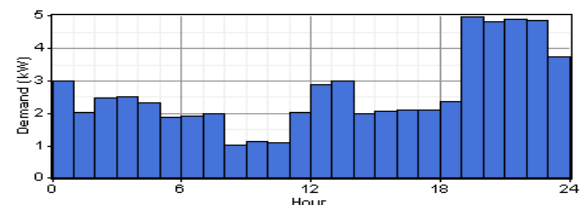


Fig. 3: Daily load profile

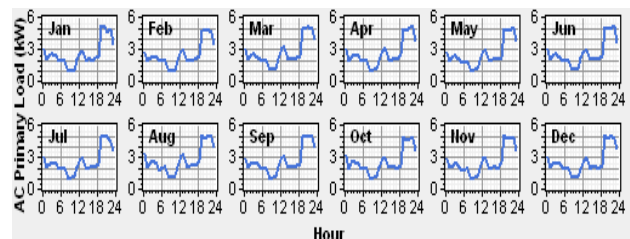


Fig. 4: AC primary monthly load profile

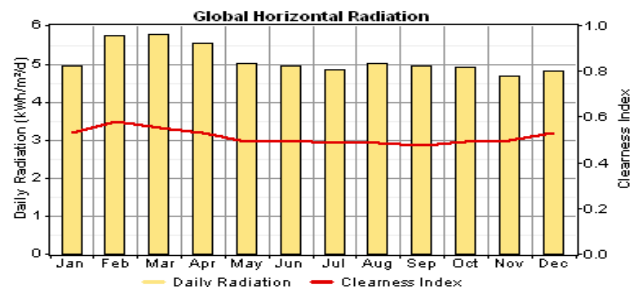


Fig. 5: Daily solar global radiation and clearness

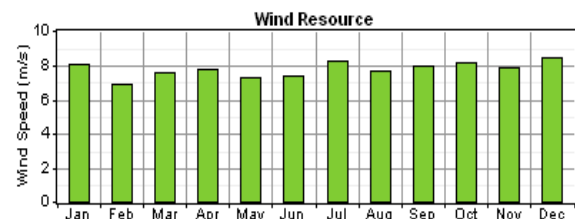


Fig. 6: Monthly wind speed data

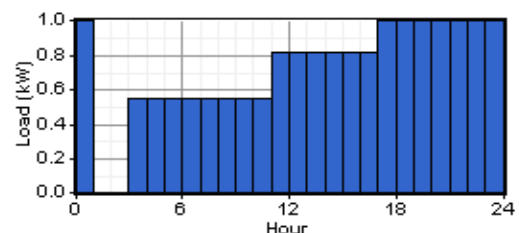


Fig. 7: Daily load profile

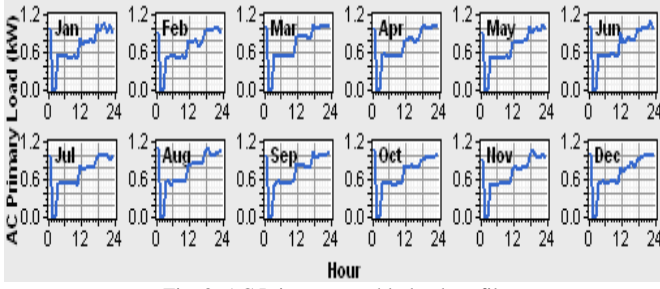


Fig. 8: AC Primary monthly load profile

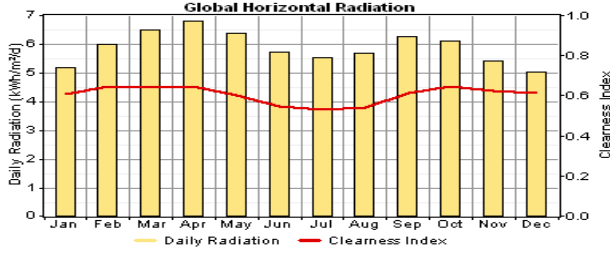


Fig. 9: Daily solar global radiation and clearness

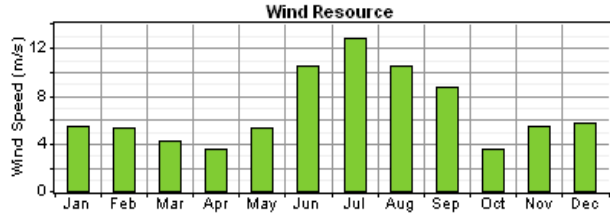


Fig. 10: Monthly wind speed data

III. SYSTEM CONFIGURATION AND MODELING

The hybrid microgrid system is a combination of PV panels, wind turbines, generators and other components such as batteries and converters as shown in Figure 11. For each of these components, prices were obtained according to typical market prices in US dollars. In the considered system, a PV array is used to charge a battery bank during the daytime. The deep cycle battery bank is used for electricity storage (charging) at daytime and supply DC current to inverter (discharging) at nighttime [10]. The lead acid sealed type deep cycle batteries are suitable for renewable energy power system because the charging and discharging processes can be performed continuously for several hours. Inverter (Converter) is used for the purpose of rectifying AC to DC and inverting DC to AC. The diesel generator is used for supplying power to the load when the storage capacity of the battery bank is insufficient. The generated excess electricity of generator will be useful to charge the battery bank. Table 2 presents the cost of commercially available components of the system shown in Figure 11, more technical information about the capital cost, operation and maintenance cost can be found in [11]. The expected lifetime of the system is 25 years.

The evaluation of the system in terms of economics is achieved by optimizing the total net present cost to get the optimal configuration of the hybrid system. The total net present cost (NPC) is used here to represent the life-cycle cost of a system. The life-cycle cost of analysis compares all costs

that occur within the life span of the system. The NPC includes the cost of initial construction, component replacement, maintenance, fuel, plus the cost of buying power from the grid and miscellaneous costs such as penalties resulting from pollutant emissions [11, 12]. Revenue includes income from selling power to the grid, plus any salvage value that occurs at the end of the project lifetime:

$$C_{NPC} = \frac{C_{ann,tot}}{CRF(i, R_{proj})} \quad (1)$$

where,

$C_{ann,tot}$ - total annualized cost (\$/year)

i - annual interest rate (%)

R_{proj} - project lifetime (year)

where CRF is the capital recovery factor and can be found from:

$$CRF(i, N) = \frac{i(1+i)^N}{(1+i)^N - 1} \quad (2)$$

where N is the number of years.

The initial capital cost of a component is used to calculate the total installed cost of that component at the beginning of the hybrid system. The equation used to obtain this result is:

$$C_{acap} = C_{cap} \times CRF_{proj} \quad (3)$$

where,

C_{acap} - Annualized capital cost

CRF_{proj} - CRF project

The salvage value is the value remaining in a component of the power system at the end of the hybrid system lifetime. The system is assumed to follow a linear depreciation in the value of components and the salvage value is based on the replacement cost rather than the initial capital cost, meaning that the salvage value of a component is directly proportional to its remaining life and this can be expressed mathematically as:

$$S = C_{rep} \frac{R_{rem}}{R_{comp}} \quad (4)$$

where,

R_{rem} - remaining life of component

R_{comp} - component lifetime (year)

C_{rep} - replacement cost (\$)

The following levelized cost of energy (COE) is the average cost per kWh of useful electrical energy produced by the system. To calculate the COE, the annualized cost of producing electricity is divided by the total useful electric energy production. The equation for the COE is as follows:

$$COE = \frac{C_{ann,tot} - C_{boiler} E_{thermal}}{E_{prim,AC} + E_{prim,DC} + E_{def} + E_{grid,sales}} \quad (5)$$

where,

- $C_{ann,tot}$ - total annualized cost of system (\$/year)
- C_{boiler} - boiler marginal cost (\$/kWh)
- $E_{thermal}$ - total thermal load served (kWh/year)
- $E_{prim,AC}$ - AC primary load served (kWh/year)
- $E_{prim,DC}$ - DC primary load served (kWh/year)
- E_{def} - deferrable load served (kWh/year)
- $E_{grid,sales}$ - total grid sales (kWh/year)

TABLE III
THE COMPONENT COSTS OF MICROGRID SYSTEM

| Components | Initial cost, \$ | Replacement cost, \$ |
|----------------------------|------------------|----------------------|
| Solar PV panel (75W) | 548 | 92 |
| wind turbine (0.6kW) | 6,048 | 5,901 |
| diesel generator (1kW) | 2,508 | 2,360 |
| Inverter/Converter (45kW) | 14,264 | 14,264 |
| Single Battery (2V, 600Ah) | 504 | 492 |

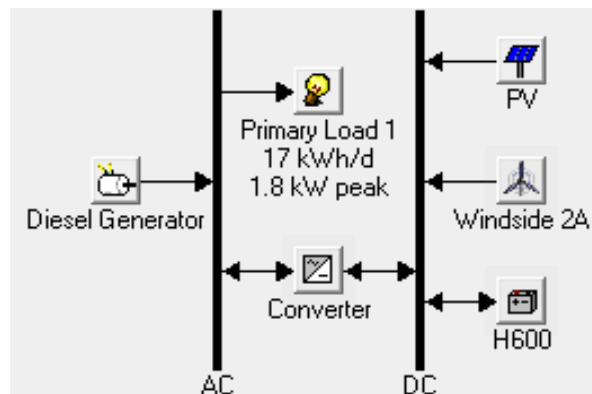


Fig. 11: Design of hybrid microgrid system

IV. RESULTS AND DISCUSSION

The hybrid renewable energy system is assumed to be installed in Langkawi and Socotra Islands. For these sites, the collected data of wind speed, ambient temperature and load demand are plotted in section 2. This data with the initial cost of

components are used to calculate the power produced by the renewable resources in order to determine the optimal hybrid microgrid system in terms of total net present cost (TNPC). The feasibility study of using renewable energy in two Islands was carried out considering two cases.

The first case, when the applied load into the microgrid hybrid system of each Island is different as given in Table 1. Tables 3 and 4 show the obtained results of TNPC for Langkawi and Socotra Islands respectively. As seen from Table 3 and 4, the optimal configuration of the proposed system for Langkawi and Socotra is a PV array-diesel generator hybrid system. It is recommended to install for Langkawi a 1kW PV array, 3kW diesel generator, 60 Hoppecke 60PzS600 battery bank with a 10kW converter. Over the lifetime of the system, the total net present cost which is the sum of the capital cost and the total energy production is \$397,646. The generator will be running approximately 7,762 hours per year and the annual fuel usage of the generator would be 7,685 liters. As for Socotra, the recommended system is a 3kW PV array, 2kW diesel generator, 30 Hoppecke 60PzS600 battery bank with a 5kW converter. Over the lifetime of the system, TNPC is \$138,499. The generator will be running approximately 542 hours per year and the annual fuel usage of the generator would be 347 liters.

TABLE IIIII
LANGKAWI MICROGRID FOR DIFFERENT LOADS

| System Configuration s | Initial Capital (\$) | Total Net Present Cost (\$) | Cost of Energy (\$/kWh) |
|------------------------|----------------------|-----------------------------|-------------------------|
| S+G+B+C | 66,947 | 397,646 | 1.109 |
| G+B+C | 31,777 | 401,910 | 1.121 |
| S+W+G+B+C | 72,995 | 405,496 | 1.131 |
| W+G+B+C | 37,825 | 409,536 | 1.142 |

TABLE IV
SOCOTRA MICROGRID FOR DIFFERENT LOADS

| System Configuration s | Initial Capital (\$) | Total Net Present Cost (\$) | Cost of Energy (\$/kWh) |
|------------------------|----------------------|-----------------------------|-------------------------|
| S+G+B+C | 108,835 | 138,499 | 1.420 |
| S+W+G+B+C | 129,335 | 166,729 | 1.710 |
| W+G+B+C | 41,887 | 215,370 | 2.209 |
| G | 17,000 | 266,634 | 2.735 |

where, S - Solar Panel; W -Wind Turbine; G - Diesel Generator; B – Battery; C - Converter

The second case, when the same load demand (17kWh/d) is applied into the microgrid hybrid system of each Island. The obtained results of TNPC for Langkawi and Socotra are presented in Tables 5 and 6 respectively. From Table 5, it can be noted that the optimal configuration of the proposed system for Langkawi is a Wind-diesel generator hybrid system. It is recommended to install a 1 Windside 2A, 1kW diesel generator, 20 Hoppecke 60PzS600 battery bank with a 1kW

converter. Over the lifetime of the system, the total net present cost is \$118,660. The generator will be running approximately 6,857 hours per year and the annual fuel usage of the generator would be 2,262 liters. Referring to Table 6, the optimal configuration of the proposed system for Socotra is a 3kW PV array, 2kW diesel generator, 30 Hoppecke 60PzS600 battery bank with a 5kW converter. Over the lifetime of the system, TNPC is \$138,499. The generator will be running approximately 542 hours per year and the annual fuel usage of the generator would be 347 liters.

The hybrid system includes a traditional fossil-fuel-fired generator and thus pollutants originate from the consumption of fuel and biomass in the generator. Table 7 shows the total amount of each pollutant produced annually by the diesel generators for the optimal configuration. The types of pollutant released from diesel generators are carbon dioxide (CO₂) and Nitrogen oxides (NO_x). These results are based on the amount of diesel fuel burned and the hours of generators run-time. Of the two islands, a diesel generator in Langkawi has the highest amount of pollutant emissions in a year, whereas the lowest level of pollution released from diesel generators would be in Socotra Island.

TABLE V
LANGKAWI MICROGRID FOR THE SAME LOADS

| System Configuration s | Initial Capital (\$) | Total Net Present Cost (\$) | Cost of Energy (\$/kWh) |
|------------------------|----------------------|-----------------------------|-------------------------|
| W+G+B+C | 18,953 | 118,660 | 1.217 |
| S+G+B+C | 36,386 | 121,672 | 1.248 |
| S+W+G+B+C | 42,434 | 129,578 | 1.329 |
| G | 5,016 | 148,568 | 1.524 |

TABLE VIV
SOCOTRA MICROGRID FOR THE SAME LOADS

| System Configurations | Initial Capital (\$) | Total Net Present Cost (\$) | Cost of Energy (\$/kWh) |
|-----------------------|----------------------|-----------------------------|-------------------------|
| S+G+B+C | 108,835 | 138,499 | 1.420 |
| S+W+G+B+C | 129,335 | 166,729 | 1.710 |
| W+G+B+C | 41,887 | 215,370 | 2.209 |
| G | 17,000 | 266,634 | 2.735 |

TABLE VVVI
POLLUTANT EMISSION FOR OPTIMAL CONFIGURATION

| Location | Carbon Dioxide (kg/year) | Nitrogen Oxides (kg/year) |
|-----------------|--------------------------|---------------------------|
| Langkawi Island | 5,957 | 131 |
| Socotra Island | 913 | 20.1 |

V. CONCLUSION

Islands represent a big niche market for the application of Alternative Energy technologies and are very important when it

comes to the promotion of renewable energy worldwide. The configuration of the optimal hybrid microgrid is selected based on the best components and sizing with appropriate operating strategy to provide an efficient, reliable and cost-effective system. The optimal hybrid microgrid selected in terms of total net present cost is a PV-diesel generator hybrid system for Langkawi and Socotra Islands when specific loads are applied. However, the optimal system for Langkawi Island is a Wind-diesel generator hybrid system and for Socotra Island is a PV-diesel generator hybrid microgrid system when a similar load is applied into hybrid microgrid system of the two Islands. The Feasibility study of a hybrid microgrid system in Langkawi and Socotra Islands will provide great opportunities as a platform of renewable energies using the future possibilities of distributed generation in remote areas.

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